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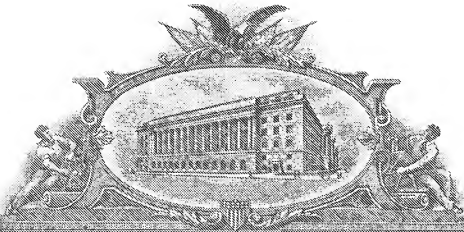
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Additional inventors are being named on the _____ separately numbered sheets attached hereto					
TITLE OF THE INVENTION (500 characters max)					
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Direct all correspondence to: <b>CORRESPONDENCE ADDRESS</b>					
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(Page 1 of 1)

Respectfully submitted,

Date March 30, 2004

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**USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT**

## FREQUENCY SHIFT COMPENSATION, SUCH AS FOR USE IN A WIRELESS METER-READING ENVIRONMENT

### BACKGROUND

Wireless transceivers often utilize a radio frequency (RF) signal to send data between a transmitter and a receiver. In an ideal frequency modulated (FM) system, the frequency of the transmitter and receiver would be matched. Even a slight difference in frequency can lead to a reduction in the performance of the system.

Compensating for frequency shifting between the transmitter and receiver can lead to losses in both the cost and the accuracy of a system. In order to keep the costs down, less expensive oscillator circuits are often used. Errors in frequency can result from temperature shifts, aging, mechanical shock, and manufacturing tolerances. These errors tend to be randomly distributed and change over time. As a result, frequency accuracy may drift. If the drift is too great, then the receiver may not be able to decode the incoming received signal.

To compensate for this difference in frequency between the transmitter and the receiver, one of two things typically occurs: either a system needs to be designed with stable and accurate reference oscillators, which in many cases are expensive, or the bandwidth of the system needs to be widened so that the shifts in frequency fall within the bandwidth of the receiver. Widening the bandwidth can lead to a reduction in the signal-to-noise ratio (SNR) of the system which leads to a decrease in the performance of the system. The SNR measures the strength of the signal relative to the background noise and is measured in decibels (dB). Maximizing the SNR can increase the performance of the system.

Specific modulation schemes can be used to compensate for the shift in frequency between the transmitter and the receiver. One modulation scheme, called quadrature modulation, subdivides a binary data stream into pairs of two

bits and represents each pair with one of four levels before performing modulation. Quadrature phase shift keying (QPSK) refers to a type of quadrature modulation in which two data bits represent four different possibilities: 0 degrees, 90 degrees, 180 degrees, and -90 degrees. These four levels correspond to positions around the unit circle when the unit circle represents phase. One drawback of QPSK is that large phase changes at the end of each symbol (pair of two data bits) can lead to undesirable transitions if the waveform is to be filtered and subsequently processed by a nonlinear power amplifier. Embodiments of the invention do not use QPSK because the frequency of the transmitted data changes but the phase does not change.

Another popular type of modulation is binary frequency shift keying (BFSK). In BFSK, binary baseband data selects one of two carrier frequencies with equal amplitudes: one carrier frequency corresponds to a "1" and the other carrier frequency corresponds to a "0". In effect, the "frequency" is "shifted" to "key" the data. Since the frequency shifts or "keys" between two frequencies, the process is referred to as binary frequency shift keying (BFSK).

Automatic utility meter reading represents one application that employs wireless transceivers. While these transceivers employ QPSK or BFSK, they suffer from frequency shifting. Meter reading endpoints tend to be costly and performance sensitive, so anything that can be done to reduce the cost and to increase the range of the system would be beneficial. Since the reading equipment tends to be less cost sensitive, stable frequency sources can be used.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram illustrating components within a meter reading device that may employ a frequency compensating process under one embodiment of the invention.

Figure 2 is a block diagram illustrating an example of a system in which the frequency compensating process may be employed.

Figure 3A is a diagram of two baseband signals, the top signal representing the frequency shift during the transmission of a "1" and the bottom signal representing the frequency shift during the transmission of a "0", for the case when a local oscillator (LO) in a transmitter and a receiver are matched.

Figure 3B is a diagram of two baseband signals, the top signal representing the frequency shift during the transmission of a "1" and the bottom signal representing the frequency shift during the transmission of a "0", for the case when the LO in the transmitter and the receiver are not matched.

Figure 4 is a block diagram illustrating components of a zero IF (intermediate frequency) receiver.

## DETAILED DESCRIPTION

The invention will now be described with respect to various embodiments. The following description provides specific details for a thorough understanding of, and enabling description for, these embodiments of the invention. However, one skilled in the art will understand that the invention may be practiced without these details. In other instances, well-known structures and functions have not been shown or described in detail to avoid unnecessarily obscuring the description of the embodiments of the invention.

It is intended that the terminology used in the description presented below be interpreted in its broadest reasonable manner, even though it is being used in conjunction with a detailed description of certain specific embodiments of the invention. Certain terms may even be emphasized below; however, any terminology intended to be interpreted in any restricted manner will be overtly and specifically defined as such in this Detailed Description section.

As described below, a transmitter first sends a known symbol at a low data rate, which represents the two data states for the transmitted binary data. Because the data rate is very low, the receiver can widen its bandwidth and maintain the same sensitivity it would have during a normal, high data rate transmission. Sensitivity refers to the minimum signal level that the system can

detect with an acceptable signal-to-noise ratio (SNR). The receiver need only widen its bandwidth to the worst possible case frequency shift between the transmitter and receiver using reference and deviation errors to determine this worst possible case frequency shift.

As explained below, one embodiment of the invention employs a zero IF (intermediate frequency) receiver. In a normal zero IF receiver, an incoming frequency modulated (FM) signal mixes with a reference signal at the exact or expected carrier frequency of the transmitted signal. This ensures a desired frequency for efficient radio transmission and produces an output baseband signal equal to an original FM modulation deviation. The original FM modulation deviation refers to the difference of the frequency of a transmitter's local oscillator (LO) from the known center frequency of a receiver. The resulting signal is then demodulated to recover the original data stream with minimal noise. If the transmitter and the receiver are not exactly matched in frequency, then a received signal, when mixed down to baseband, contains an error signal in addition to a modulated signal. The error signal equals the difference in frequency between a transmitter carrier frequency and a receiver reference frequency. If this error is sufficiently large, it may reduce the performance of the receiver in a meter-reading device.

#### Suitable System and Application

Typical meter reading devices come in two forms: manual input and automatic meter reading (AMR) devices. Manual input devices typically employ a keypad and display on a portable device. A meter reader or operator views a meter and inputs data associated with that read using the keypad. Automatic meter reading devices periodically gather data from a meter automatically, and transmit it to a collector. There is a need, however, to improve upon existing systems.

Referring to Figure 1, one example of a reader 100 is shown as having a processor 112 that couples to the keyboard 102 and display device 104. Various

other output devices may be employed in addition to, or in lieu of, the visual display device, such as a printer, plotter, speakers, tactile or olfactory output devices, etc. Likewise, various other input devices may be employed in addition to, or in lieu of, the keyboard, such as a pointing device (for example, a mouse or track ball), touch-sensitive display, track pad, a microphone, joystick, pen, game pad, scanner, digital camera, video camera, etc. While not shown, the reader 100 may include a trigger switch, possibly in conjunction with a handle. Other input devices may include a keyboard, and so forth. As described herein, a reduced number of keys may be provided over standard meter reading devices.

A memory 114 stores data (e.g., images) and software routines executed by the processor, while a power source 106, such as rechargeable batteries, provide power to the reader 100. The memory may include any type of computer-readable media that can store data accessible by the reader 100, such as magnetic hard and floppy disk drives, optical disk drives, magnetic cassettes, tape drives, flash memory cards, digital video disks (DVDs), Bernoulli cartridges, RAMs, ROMs, smart cards, etc. The reader 100 also includes a radio transceiver 108 for capturing automatic meter reading (AMR) data.

While Figure 1 shows a single processor 112, those skilled in the relevant art recognize that the reader 100 may employ multiple processors that divide tasks of routines. The term "processor" is generally used herein, refers to any logic processing unit, such as one or more central processing units (CPU), digital signal processors (DSP), application-specific integrated circuits (ASIC), etc. While the processor 112 and other components of the reader 100 are shown as separate blocks, some or all of these blocks may be monolithically integrated into a single chip.

Each of the blocks shown in Figure 1 are of a type known in the art, and one skilled in the relevant art would be able to use such circuits or subsystems to practice aspects of the invention. The internal details of these blocks are neither part of, nor critical to, aspects of the invention. Therefore, a detailed description of the internal circuit operation is not required for each of these blocks. Similarly,

relevant functionality with respect to aspects of the reader 100 are described in detail herein.

The radio transceiver 108 permits wireless transmission and/or reception of signals. Other known modules may be included, such as a global positioning system (GPS) module, a telescoping pole or handle to suspend the reader 100 at a considerable distance from the ground to gather images from meters positioned at above ground-level locations, and so forth.

Referring to Figure 2, another example of an automatic meter-reading system is shown as a system 200 that includes a meter-reading data collection system having multiple meters 220 coupled to utility-consuming devices (not shown), such as electric, gas, or water consuming devices or locations. In this illustrated embodiment, each meter 220 includes an encoder receiver/transmitter module (ERT) 224, which serves as a data collection endpoint. The ERTs 224 encode consumption, tamper information, and other data from the meters 220 and communicate such information to a CCU 228. The communication of this data may be accomplished via radio-to-radio data collection systems such as handheld, mobile automatic meter reading or fixed network. The ERTs 224 can be retrofitted to existing meters or installed on new meters during the manufacturing process. In a system for electrical metering, the ERTs 224 may be installed under the glass of new or existing electric meters 220 and are powered by electricity running to the meter. Gas and water ERTs 224 can be attached to the meter 220 and powered by long-life batteries.

As shown in Figure 2, a group of ERTs 226 communicates with one of the CCU devices 228, which in turn feeds collected data to a head-end system 230 via periodic uploads. This may occur on an ongoing basis (e.g., every half-hour) or as otherwise needed. The CCUs 228 may be implemented as neighborhood concentrators that read the ERTs 224, process data into a variety of applications, store data temporarily, and transport data to the head-end system 230 as needed. In some embodiments, the CCUs 228 can be installed on power poles or streetlight arms (not shown).

Further details about the system of Figure 2 and similar systems can be found in the following commonly assigned patent applications: U.S. Patent Application No. 09/911,840, entitled "Spread Spectrum Meter Reading System Utilizing Low-speed/High-power Frequency Hopping," filed July 23, 2001; U.S. Patent Application No. 09/960,800, entitled "Radio Communication Network for Collecting Data From Utility Meters," filed September 21, 2001; and U.S. Patent Application No. 10/024,977, entitled "Wide Area Communications Network for Remote Data Generating Stations," filed December 19, 2001.

Both of the above systems, the reader 100 of Figure 1 and the system 200 of Figure 2, may employ RF receivers, such as a zero IF receiver. A zero IF receiver mixes a received signal directly to a baseband frequency rather than to an intermediate frequency. As a result, error detection occurs at the baseband frequency rather than at a higher frequency. Error detection at baseband frequencies presents an advantage over error detection at higher frequencies since lower frequencies may be measured by inexpensive microcontrollers.

Embodiments of the invention utilize a key property of a zero IF receiver. A typical frequency modulated (FM) receiver receives a signal and mixes it with another frequency, such as 916 MHz, and subsequently mixes it with another frequency, such as 846 MHz, to get a 70 MHz difference signal that is processed. With a zero IF receiver, however, a 916 MHz signal mixes with a local 916 MHz signal. If the FM modulation deviates by  $\pm 10$  kHz, then this produces a plus or minus signal of 10 kHz which is then filtered and processed. It is generally easier to filter a lower frequency signal since there are, for example, effective, existing, and relatively inexpensive 12-pole filters.

In a zero IF receiver, a local oscillator (LO) is tuned to the center frequency of an intended receive channel – for instance, the frequency of the carrier. The received signal deviates about this center frequency at some known deviation amount. For example, the center of the channel might be at 433 MHz and an RF signal on this channel modulates by  $\pm 10$  kHz. The RF signal would then be 433.01 MHz for a digital one and 432.99 MHz for a digital zero. Low cost micro-

controllers cannot measure high frequency signals of 433 MHz, but they can measure frequencies in the 10 kHz range.

In the zero IF system, a mixer downconverts the frequency of the received signal. In other words, the local oscillator (LO) shifts the frequency of the received signal to obtain a desired frequency band for subsequent demodulation. In a digital radio, this data is typically a "1" or a "0". Sending a "1" means that the frequency is increased, and sending a "0" means that the frequency is decreased. Figure 3A shows two centered baseband signals that have matched local oscillators in the transmitter and the receiver. The top baseband signal represents the frequency shift, " $F_1 - F_2$ ", when transmitting a "1". The bottom baseband signal represents the frequency shift, " $F_1 - F_2$ ", when transmitting a "0". The top and bottom baseband signals are matched, meaning that they have the same frequency and that no error has been detected between the two. The baseband signals corresponding to "1" and "0" are matched because the output of the LO has the same frequency as the received signal carrier wave.

Figure 3B shows two baseband signals, representing the frequency shifts when transmitting a "1" and a "0", that have a local oscillator in the transmitter and receiver that are not matched, introducing an error and causing the baseband signals to be un-centered. The frequency of the baseband signal during a "1" no longer matches the frequency of the baseband signal during a "0" because the frequency of the received signal carrier wave differs from the frequency of the output of the receiver's LO. As a result, the error may diminish the ability of the decoder to reconstruct the original data, and the radio sensitivity might decrease. If the error is sufficiently large, then the decoder may not be able to decode any data.

Figure 4 shows components of a zero IF receiver 400 which may employ aspects of the invention. An amplifier 404 amplifies a received signal 402 to produce an amplified RF signal F1. A local oscillator (LO) 408 in the receiver 400 produces a periodic signal at the same or expected frequency as a received carrier wave.

Figure 4 shows that the LO 408 generates a signal F2 that mixes with the amplified RF signal F1 in a mixer 406. The mixer 406 effectively downconverts the received signal 402, translating the received signal's frequency spectrum to a lower frequency to facilitate subsequent demodulation. In an ideal case, the mixer 406 generates a signal representing the difference between F1 and F2, namely "F1-F2". "F1-F2" represents the deviation of the transmitter from the expected center frequency, which in this example is 433 MHz. The output signal from the mixer 406, "F1-F2", enters into a variable lowpass filter 410 with an ideal frequency response in order to limit the bandwidth of the receiver 400 for the purpose of decreasing interference from unwanted signals. The variable lowpass filter 410 passes the magnitudes of the frequency components of the "F1-F2" signal that lie within the passband of the filter. The variable lowpass filter 410 also eliminates frequency components outside the passband. Figure 4 shows that the variable lowpass filter 410 generates a pair of baseband signals 414, I (in-phase) and Q (quadrature). I and Q 414 enter a demodulator 412, which reconstructs the original data signal with minimal noise. The two baseband signals 414, I and Q, are used to demodulate the data. However, only one of the signals, I or Q, is needed to detect the baseband frequency error between the received signal 402 and the LO 408. As explained below, the receiver 400 adjusts the LO 408 to a new centering frequency for more accurate decoding. (An example of a zero IF receiver chip that provides I and Q output signals is produced by BlueChip of Norway.)

In a zero IF receiver, the downconversion of the frequency spectrum of the received signal 402 to a lower frequency to facilitate demodulation results in the mixer 406 typically generating baseband signals 414 I (in-phase) and Q (quadrature). I and Q 414 represent 10 kHz square waves in this example. When F1 equals 433 MHz, 433.01 MHz corresponds to "F1 + 10 kHz" while 432.99 MHz corresponds to "F1 - 10kHz".

The system 400 employs one of the baseband signals 414, I or Q, to detect a frequency error between the received signal F1 402 and the signal F2 generated by the LO 408. The frequency error can be found by measuring the frequency

shift during the transmission of a "1" and a "0". By subtracting the frequency shift during the "0" state from the frequency shift during the "1" state and dividing the difference by two, the frequency error between F1 and F2 can be obtained. For example, if the endpoint frequency drifts high by 2 kHz, then the output of the mixer 206 would be 12 kHz during a "1" and 8 kHz during a "0". From this frequency error, the receiver 400 determines the new centering frequency and adjusts the LO 408 to regain a good match for I and Q. The adjustment of the LO 408 ensures more accurate decoding and allows the system to compensate for frequency shifting. The method described above differs from alternative embodiments since it only needs a single one and a single zero to calculate the frequency error between F1 and F2.

In particular, the receiver 400 examines the baseband signals 414 during an initial phase of communications when a known low data rate "1" or "0" symbol is sent. The receiver 400 increases the bandwidth of the receiver filter to allow an estimated worst case frequency error to pass. The system 400 may not need to adjust for bandwidth, depending on the expected frequency error. If the worst case error exceeds the bandwidth of the filter, then the filter bandwidth must be increased. If the bandwidth is sufficient to accept the worst case frequency error, then the filter may be left unchanged.

A microcontroller 420 provides a wide passband signal to the variable lowpass filter 410. For example, if the lowpass filter, during normal operation, has a lowpass gap of approximately 30 kHz, then the microcontroller 420 causes the variable lowpass filter to widen its bandgap to approximately 60 kHz, centered on the expected baseband frequency. With the widened bandwidth, the microcontroller 420 then analyzes the frequency error between a "1" and a "0" in this example, during the initial communication phase.

By examining the relationship of the baseband signal frequency during the "1" and "0" portions of the known low rate symbol, the receiver 400 can determine this frequency error and adjust its local oscillator 408 until the signal becomes centered. Thus, the microcontroller 420 provides a frequency compensation signal to the LO 408, which in response, adjusts its frequency to match that of the

received baseband signal 402. The microcontroller 420 also provides a filter adjustment signal to the variable lowpass filter 410 to allow the bandwidth to return to its original, narrower state. Thus, the filter bandwidth again reduces or eliminates interference from unwanted signals. When the actual data follows from the known, low rate data symbol, the receiver 400 is matched in frequency with the transmitter, and the sensitivity of the receiver 400 improves. Increasing the bandwidth of the baseband filter reduces sensitivity for decoding but enables the receiver 400 to find the carrier frequency. Once the carrier frequency is found, the receiver 400 can calculate the error in the two data bits and center the LO 408, reducing the baseband bandwidth to regain sensitivity. Calculating the frequency error between F1 and F2 in this embodiment requires the receiver 400 to receive only a single one and a single zero. Under an alternative embodiment, the receiver need only analyze one bit, a "1" or a "0", if the receiver knows that the first bit is always a "1" or a "0". Thus, this alternative can permit for quicker frequency compensation but can require greater accuracy during the initial communication phase.

The receiver 400 uses un-decoded data, which tends to be fast, precise, and accurate. Traditionally, the use of un-decoded signals to determine frequency error has been ignored in favor of using decoded signals. The receiver 400, which utilizes un-decoded signals to determine frequency error, can be used to develop stable, low cost, low power meter-reading transceivers and can use them in a narrow band, high performance system.

In another alternative embodiment, a decoded data output determines a frequency center. If the decoded data output is asymmetrical, then an offset in the frequency may occur. The LO is adjusted and the decoded data output is checked again for symmetry. This alternative takes several ones and zeros to determine the frequency error that is then removed by a successive approximation of symmetry errors. If the endpoint frequency is too far off, then a data decoder may not be able to decode data out of the frequency deviation and the receiver will have to search for the endpoint signal. This method relies on decoded data which tends to be prone to error due to a mismatch in the frequencies of the

received signal and the signal from the LO. Using decoded data tends to lead to a slower system that consumes more power.

The above detailed descriptions of embodiments of the invention are not intended to be exhaustive or to limit the invention to the precise form disclosed above. While specific embodiments of, and examples for, the invention are described above for illustrative purposes, various equivalent modifications are possible within the scope of the invention, as those skilled in the relevant art will recognize. For example, while certain circuit configurations are provided, alternative embodiments may employ different modules, blocks or functions to achieve similar functionality or results.

Those skilled in the relevant art will appreciate that the invention can be practiced with other communications, data processing or computer system configurations, including: Internet appliances, hand-held devices (including personal digital assistants (PDAs)), wearable computers, all manner of cellular or mobile phones, multi-processor systems, microprocessor-based or programmable consumer electronics, set-top boxes, network PCs, mini-computers, mainframe computers and the like. Indeed, the terms "computer," "host" and "host computer" are generally used interchangeably, and refer to any of the above devices and systems, as well as any data processor. Aspects of the invention can be embodied in a special purpose computer or data processor that is specifically programmed, configured or constructed to perform one or more of the computer-executable instructions explained in detail herein. Aspects of the invention can also be practiced in distributed computing environments where tasks or modules are performed by remote processing devices, which are linked through a communications network. In a distributed computing environment, program modules may be located in both local and remote memory storage devices.

Aspects of the invention may be stored or distributed on computer-readable media, including magnetically or optically readable computer discs, as microcode on semiconductor memory, nanotechnology memory, or other portable data storage medium. Indeed, computer-implemented instructions, data structures, screen displays, and other data under aspects of the invention may be distributed

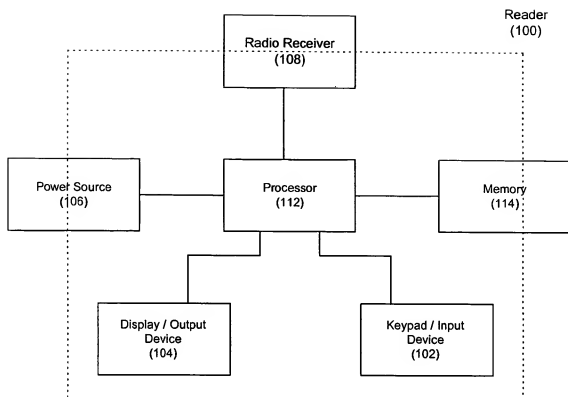
over the Internet or over other networks (including wireless networks), on a propagated signal on a propagation medium (e.g., electromagnetic wave(s), a sound wave(s), etc.) over a period of time, or may be provided on any analog or digital network (packet switched, circuit switched or other scheme). Those skilled in the relevant art will recognize that portions of the invention reside on a server computer, while corresponding portions reside on a client computer such as a mobile device.

Words in the above detailed description using the singular or plural number may also include the plural or singular number respectively. Additionally, the words "herein," "above," "below," and words of similar import, when used in this application, shall refer to this application as a whole and not to any particular portions of this application. When the claims use the word "or" in reference to a list of two or more items, that word covers all of the following interpretations of the word: any of the items in the list, all of the items in the list, and any combination of the items in the list.

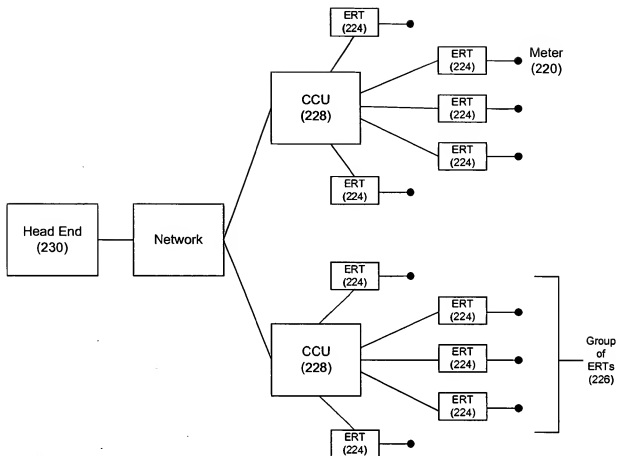
The teachings of the invention provided herein can be applied to other systems, not necessarily the system described herein. These and other changes can be made to the invention in light of the detailed description. The elements and acts of the various embodiments described above can be combined to provide further embodiments.

These and other changes can be made to the invention in light of the above detailed description. While the above description details certain embodiments of the invention and describes the best mode contemplated, no matter how detailed the above appears in text, the invention can be practiced in many ways. Details of configurations, functions, etc. may vary considerably in implementation details, while still being encompassed by the invention disclosed herein. As noted above, particular terminology used when describing certain features, or aspects of the invention should not be taken to imply that the terminology is being re-defined herein to be restricted to any specific characteristics, features, or aspects of the invention with which that terminology is associated. In general, the terms used should not be construed to limit the invention to the specific embodiments

disclosed in the specification, unless the above Detailed Description section explicitly defines such terms. Accordingly, the actual scope of the invention encompasses not only the disclosed embodiments, but also all equivalent ways of practicing or implementing the invention.



**Figure 1: Components of Meter-Reading Device that employs Frequency Compensation**



**Figure 2: System that employs Frequency Compensation Process**



Figure 3A: Centered Baseband Signals



Figure 3B: Un-centered Baseband Signals

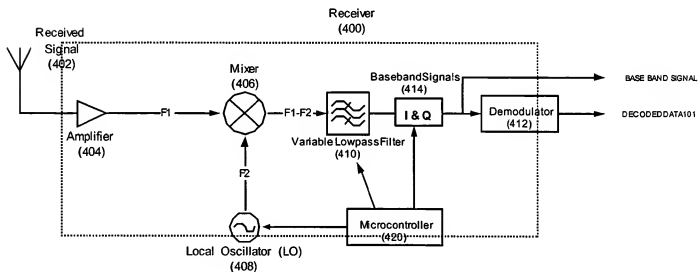


Figure 4: Components of Zero IF Receiver